Genetic-based Machine Learning using Hardware Accelerator

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Abstract: This paper discusses new genetic-based learning system. The proposed learning system adopts new if-then rules for acquiring a strategy of the robots. Moreover, it introduces novel hardware accelerator in order to reduce simulation time, since the genetics-based machine learning requires very long computational time. Experiments using quasi-ecosystem demonstrate not only the effectiveness of the proposed learning algorithm, but also that of the proposed architecture of hardware accelerator.

Key-Words: Evolutionary robotics, Hardware accelerator, if-then rules, Genetic-based machine learning, Quasi-ecosystem

1 Introduction

Recently, intelligent robots have been applied to various fields[1]. An intelligent robot can generally recognize its environment, make decisions, take actions. An intellectual robot's action is learned autonomously. However, it is impossible to design a robot's controller in consideration of all situations in advance. Therefore, there are some researches which make a robot learn action using neural network and fuzzy system. Evolution robotics is one of the autonomous learning and its approaches are based on Genetic Algorithm (GA)[2],[3]. The GA was proposed by Holland as an algorithm for probabilistic search, learning, and optimization. It is based in part on the mechanism of biological evolution and Darwin's theory of evolution. The evolutionary robotics in quasi-ecosystems[4]-[6] have been proposed and have achieved the measure success. However, GA has the inherent problem of requiring substantial processing time, because they are multi-point search algorithms. Therefore, the computer simulation of evolutionary robotics in the quasi-ecosystem requires a very long computational time.

In this paper, we propose a novel approach of evolutionary robotics in a quasi-ecosystem using a hardware accelerator in order to realize high-speed calculation. Examples of GA hardware have been proposed by Scott et al. [7], Graham et al. [8], and Imai et al. [9]. Scott et al. developed a processor element of GA for parallel processing and proved the effectiveness of the parallel technique. However, most of these previous works deal with small-scaled problems. Moreover, no studies have ever seen the hardware accelerator for evolutionary robotics. The proposed hardware accelerator, implemented on the field-programmable gate array (FPGA), achieves high-speed the genetics-based machine learning.

2 Evolutionary robotics

We deal with multiple robots interacting with a quasi-ecosystem model composed of two species of fishes and plankton as shown in Fig.1. A relationship of the quasi-ecosystem is shown in Fig.2.

![Fig.1 Example of quasi-ecosystem](image-url)
The fish has energies and consume them with progress of time. And then, the energies are supplemented by eating plankton. The fish will die if their energies are lost. However, if the number of planktons exceeds a threshold, the inside of water will be short of oxygen and all fish will become extinct.

On the other hand, the plankton increases according to regulation. Basically, the aim of multiple robots is to maintain the numerical balance of fishes and plankton. A set of decision rules of each robot is regarded as an individual in GA. That is, each robot has a candidate rule set. Therefore, a chromosome for rule set is represented in Fig.3.

Each rule set includes if-then rules. In this way, the rule set is evolved in the robot itself. The robot has a sensor in order to recognize environment. The measurement range of a sensor is 3x3 centering on itself. And then, moving ranges are adjoining four directions as shown in Fig.4. The robots also have energies and consume them with moving. The robots also have energies and consume them with moving. The energies are supplemented by eating plankton like the fish.

Therefore, an action of a robot is six kinds, which are movement in four directions, removal of plankton, or stillness. A robot determines action by information of the number of plankton in sensing range, energy parameter, and an encounter history with plankton. Fig.5 shows the flow of which the robot decides own action.
3 Hardware accelerator

In order to reduce the calculation time, we developed a hardware accelerator. The block diagram of the hardware accelerator is shown in Fig.6.

The proposed hardware accelerator consists of interface circuit, two controllers for input/output, and holding of output data circuit and robot circuits. In the hardware accelerator, these 10 robot circuits are implemented and parallel processing is performed. The processing procedure of the hardware accelerator is as follows (see Fig.6).

\textbf{Step 1:} The data from the software side transfers to the interface circuit and the controller-1 (for input data). The interface circuit checks the error of data.

\textbf{Step 2:} The controller for input data sends the individual data and environmental data to each robot circuit.

\textbf{Step 3:} Each robot circuit is simulated.

\textbf{Step 4:} Each robot circuit sends simulation results to the holding circuit.

\textbf{Step 5:} The simulation results are sent to the controller-2 (for output), after all robot circuit have completed simulations.

\textbf{Step 6:} The controller-2 (for output) sends simulation results to the interface circuit.

The robot circuit consists of memory controller, robot state circuit, comparison of action circuit, change of robot state circuit, calculation of evaluation circuit, change of environment circuit and controller circuit as shown in Fig.7. Moreover, the evolutionary processing is conducted in the change of robot state circuit of the robot circuit.
The processing procedure of the hardware accelerator is as follows (see Fig. 7).

**Step 1:** The robot circuit receives the individual's data and the environmental data, and stores these data in each RAM (individual RAM and environmental RAM).

**Step 2:** The data loaded from the environmental RAM is compared with rule of individual's data in the comparison action circuit.

**Step 3:** The data, which is corresponding to the rule, is evaluated in the calculation of evaluation circuit, and it updates the evaluation value with the rule.

**Step 4:** The rule is simulated and evaluated. A regulated frequency repeats the simulation from Step 2 to Step 3.

**Step 5:** The rule of the individual with the highest evaluation value is sent to the control circuit as an output.

Fig. 8 shows the change of robot state circuit. It consists of three sub-circuits (selection, crossover, and mutation circuit). Fig. 9 and Fig. 10 show selection circuit, and crossover and mutation circuit, respectively.
4 Experimental results and discussion
The proposed hardware accelerator has been designed by Verilog-HDL and synthesized by the Synplicity Synplify. The frequency of hardware accelerator is set up with 33 MHz.

We implemented the hardware accelerator on an single board, which consists of two FPGAs (X2CV3000 and X2CV6000) as shown in Fig.11. Table.1 shows the gate size. In Table.1, LUTs represent combinational logics, and block rams represents memory blocks. We conduct preliminary experiments in order to decide the initial state of plankton.

Fig.12 shows the results of preliminary experiments. The horizontal axis of Fig.12 shows the existence ratio of plankton in the quasi-ecosystem. The initial state is set up with 35% form Fig.12. Experimental result comparison with software processing is shown in Table.2. In this experiment, ten robots are implemented.

Fig.11 Hardware accelerator on an shingle board

<table>
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<th>Table.1 Gate size</th>
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<tr>
<td>Resource</td>
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<tr>
<td>LUTs</td>
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<tr>
<td>Block Rams</td>
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<td>Slice</td>
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The hardware accelerator achieves 50 times the speed on average compared with software processing. Fig.13 shows the state in the quasi-ecosystem. The state after 1000th steps is the same as the initial state as shown in Fig.13. Lastly, Fig.14 shows a relationship the number of plankton and fish, and generations. The proposed hardware accelerator realized acquisition of the behavior which maintains balance as shown in Fig.14.

<table>
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<th>Table.2 Comparison of run time (200 Steps)</th>
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<td>Software processing</td>
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<td>7.324933 (s)</td>
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(1) Initial state

(2) 1000th steps

Fig.13 State in the quasi-ecosystems

5 Conclusion
In this paper, we proposed the hardware accelerator for simulation of evolutionary robotics in the quasi-ecosystem. The quasi-ecosystem model composed of fish, plankton and robots, which were in a relationship of parasitism, was simulated on the discrete cell space. The if-then rules were introduced and applied genetics-based machine learning for acquiring a strategy of the robots.
The proposed hardware accelerator achieved 50 times the speed on average compared with software processing, and realized acquisition of the behavior which maintains balance between fish and plankton. In relation to future works, simulation in complex quasi-ecosystem is the most important priority. We will also apply the proposed evolutionary robotic to simulation of artificial life.

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References: